NANOTUBE-BASED SENSORS AND SYSTEMS FOR OUTER PLANETARY EXPLORATION

F. Noca[1], B.D. Hunt[1], M.E. Hoenk[1], D. Choi[1], R. Kowalczyk[1], R. Williams[1], J. Xu[2], P. Koumoutsakos[3,4]
[1]Jet Propulsion Laboratory (bdhunt@jpl.nasa.gov), [2]Brown Univ., [3]ETH Zürich, [4]NASA Ames Research Center

Introduction: Direct sensing and processing at the nanometer scale offer NASA the opportunity to expand its capabilities in deep space exploration, particularly for the search for signatures of life, the analysis of planetary oceans and atmospheres, and communications systems. Carbon nanotubes, with their unique mechanical, electrical, and radiation-tolerant properties, are a promising tool for this exploration. We are developing devices based on carbon nanotubes, including sensors, actuators, and oscillators.

Nanotube-based Sensors and Systems:

Artificial Stereocilia. We are developing unique nanotube-based sensor technology inspired by the widespread use of stereocilia in nature [1] to "listen to the sounds of life" generated by nanoscale activity (biochemical reactions, macromolecular transport, metabolic flows, micro-organisms). Nanoscale activity is a physical signature of pre-biotic and extant life, and is expected to be omnipresent and universal, as it is not dependent on any specific (Earth-centric) biochemical composition. In particular, a nanostethoscope (based on nanotube arrays [2]) and a nanoscale force sensor [3] are being investigated. The stereocilia arrays will also be used as very sensitive, miniature, and directional acoustic sensors and as a fish-like lateral line system for the autonomous exploration of planetary oceans and atmospheres.

Nanomechanical Actuators and Oscillators. Nanotube technology enables nanoscale mechanical actuators and oscillators, based on the concept drawn from nature that motion at molecular scales can be extremely efficient. Nano-actuators will allow controllable manipulation and characterization of individual molecules, and provide an essential interface between the macroscopic and nano-worlds [3]. Nanomechanical oscillators can exhibit far higher quality factors (Qs) than electronic resonators. Nanotube-based oscillators can be made with resonant frequencies from the kHz to the GHz range coupled with small force constants [4]. These properties provide the basis for ultra-stable, low-loss, low-noise resonators needed for miniaturizing a number of essential deep space exploration technologies, including communications, radar, and signal processors.

Molecular Sieves. Separation of molecules according to size, chirality, hydrophobicity, or other properties, is an essential technique in the analysis of extraterrestrial molecules. An array of carbon nanotubes used as an electrophoretic artificial gel or as a chromatographic resin [5] will enable rapid assay of molecular properties that may be a signature of biotic or pre-biotic life (such as enantiomeric ratios). This goal requires sieving pores on the scale of 10-50 nm, which is beyond the economic limits of lithography, but well within the parameter range of carbon nanotube arrays.

Nanofluidics and Nanotube Dynamics. A computational effort is in place to help guide the design of nanotube-based systems oscillating at high frequencies and interacting with fluids and molecules [6].

Relevance to NASA Deep Space Missions: The nanometer scale of nanotubes makes them perfectly suited for the search of biomolecular or microbiological signatures of life on outer planets. In addition, nanotube-based technology does satisfy the mass and power constraints for long-life deep space missions. Finally, nanotube-based mechanical devices are exceptionally radiation tolerant due to the strong C-C bonds and the relative insensitivity of mechanical systems to radiation damage. The combination of low power, low mass, high performance, and radiation hardness makes nanotube-based devices attractive candidates for deep space missions.

References:

[1] Noca F., Hoenk M. E., Tang W., Hunt B. D. (1999) "Micro/Nano-Fabricated Stereocilia," *NASA New Technology Report*, 20780/0372b. [2] Li J., Papadopoulos C., Xu J.M., Moskovits M. (1999) *Appl. Phys. Lett.*, 75, 367. [3] Hunt B.H, Noca F., Hoenk M. (2000) "Carbon nanotube actuators and force sensors," *NASA New Technology Report, NPO-21153.* [4] Hunt B.H, Noca F., Hoenk M (2001) "Tunable Nanotube Mechanical Resonators" *NASA New Technology Report,* submitted. [5] Xu J. & Noca F. (2000) "Gel-Free Electrophoretic Device based on Carbon Nanotube Arrays," Patent Pending; *NASA New Technology Report*, 20950/0550b. [6] Walther J. & Koumoutsakos P. (2000) "A computational study of flows in carbon nanotubes," *8th Foresight Conf. Molec. Nanotech.*

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